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METROLOGY STANDARDS OF THE UNDERWATER SOUND REFERENCE DIVISION

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30 May 1973

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Metrology Standards of the Underwater Sound Reference Division

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13 ABSTRACT

Metrology standards used or planned by the Underwater Sound Reference Division and their traceability to the National Bureau of Standards are described.

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CONTENTS

FIGURES

Abstract

Metrology standards used or planned by the Underwater Sound Reference Division and their traceability to the National Bureau of Standards are described.

Problem Status

This is an interim report on the problem.

Problem Authorization

NRL Problem S02-37

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METROLOGY STANDARDS OF THE UNDERWATER SOUND REFERENCE DIVISION

Introduction

The Underwater Sound Reference Division (USRD) serves as a calibration, test, and evaluation center for underwater sound transducers and related acoustic materials. It also lends hundreds of calibrated standard hydrophones to other naval activities and contractors. As a result of these activities, a question occasionally is raised regarding traceability of USRD calibrations to the National Bureau of Standards (NBS). It is the purpose of this report to describe the metrology standards used or planned by USRD and their connection with basic standards at NBS.

NBS does not function in the areas of underwater acoustics or electroacoustics, presumably because such areas are dominated by naval rather than commercial interests. Consequently, USRD is the primary source of underwater acoustic standards and calibration services. The acoustic standards, however, are traceable to NBS through other nonacoustic parameters.

Acoustic Standards

In underwater acoustics, the principal parameter that is measured is acoustic pressure. Particle velocity or pressure gradient seldom are measured. Power or intensity are derived from the pressure and the known or estimated wave impedance. Speed of sound, acoustic attenuation, and so forth are measured so infrequently as to constitute a "research" measurement rather than a "calibration" measurement. Only pressure is measured so frequently and directly that standard procedures and instruments are indispensable. Standard procedures [1,2] have been developed and published by the American National Standards Institute with the participation of USRD staff members. Standard hydrophones of many types have been developed by USRD [3]. It is mainly the calibration of USRD standard hydrophones that should be traceable to the nonacoustic basic standards at NBS. The standard hydrophone then becomes the reference standard for other acoustic measurements involving pressure.

Hydrophone Calibration Methods and Parameters

Standard hydrophones are calibrated at USRD by one of three different primary methods--three being necessary to cover the range from infrasonic to ultrasonic frequencies and simulated depths to 6840 m. The methods are described in detail elsewhere [3], and only the fundamental calibration formulas are presented here.

Conventional Reciprocity

In a conventional reciprocity calibration the free-field voltage sensitivity M is given in terms of voltage output per unit pressure input by

$$M = \left(\frac{e_1 e_2}{e_3 i} \frac{2d}{\rho f}\right)^{\frac{1}{2}}, \tag{1a}$$

or

$$M = \left(\frac{e_1 e_2}{e_3 (e_4/R)} \frac{2d}{\rho f}\right)^{\frac{1}{2}}, \tag{1b}$$

where e is a signal voltage, i is a signal current, d is a distance, ρ is the density of the water, f is frequency, and R is an electrical resistance. It is apparent from Eqs. (1a) and (1b) that one of the three parameters e, i, and R could be eliminated; however, all three parameters are used elsewhere, so all three require a reference standard. The e and i are used in the Two Projector Null Method that is described later. The R is used in connection with the measurement of transducer efficiency.

Coupler Reciprocity

The calibration formula in coupler reciprocity is

$$M = \left(\frac{e_1 e_2}{e_3 i} \frac{2\pi f V}{\rho c^2}\right)^{\frac{1}{2}}, \tag{2a}$$

or

$$M = \left(\frac{e_1 e_2}{e_3 (e_4/R)} \frac{2\pi f V}{\rho c^2}\right)^{\frac{1}{2}}, \tag{2b}$$

where V is a volume, c is the speed of sound, and the other parameters are the same as in Eq. (1), except that ρ may be the density of a fluid other than water (usually castor oil).

Two-Projector Null Method

The calibration formula for the Two-Projector Null Method is

$$M = \left(\frac{e}{i} \frac{i_{dc}}{\rho g d}\right)^{\frac{1}{2}}, \tag{3}$$

where e is a signal voltage, i is a signal current, i_{dc} is a direct current, d is a distance (actually a height), g is the acceleration due to gravity, and ρ again is density

Environmental Parameters

In all these calibration formulas, ρ and c are functions of two environmental parameters--hydrostatic pressure p and temperature T. The sensitivity M also may be a function of hydrostatic pressure and temperature for reasons independent of the calibration measurement.

Miscellaneous Parameters

The density of some liquids used in coupler reciprocity is known only over limited ranges of hydrostatic pressure and temperature. Consequently, a density measurement with a known volume and mass is required. In some special cases, therefore, mass m becomes an additional calibration parameter.

A standard cell is fundamental to all electrical metrology. Consequently, d-c voltage e_{dc} also is considered a parameter here, even though it does not appear directly in any of the calibration formulas.

The electrical phase difference ϕ between two signals is not a conventional parameter in electroacoustical calibration measurements. Equations (1), (2), and (3) can be written in complex form, but usually it is only the magnitude of the sensitivity that is used for measuring pressure. Nevertheless, phase is included here because it is important in some special and related measurements--for example, in comparing the complex sensitivity of two or more elements of a transducer or array.

Parameter Grouping

For purposes of USRD internal responsibility, the parameters described in the previous section have been divided into the following four groups.

Electronic and Electrical Group

The parameters e, e_{dc}, i, i_{dc}, and R are inherently electronic or electrical. In addition, f, ϕ, c, and T are measured by electronic instruments and for this reason are included in this group.

Mechanical Group

The parameters d and p involve largely mechanical measurements. Here, we are concerned mostly with small distances (<0.5 m) where accuracy is most important.

Reference Data Group

The parameters ρ and g are for the most part taken from acceptable reference data. They are not measured at USRD except in some special cases--when the density of a liquid, particularly over certain ranges of

hydrostatic pressure and temperature, is unknown, for example.

Commercial Standards Group

Commercial standards for V, m, and large d ($\gtrsim$0.5 m) are readily available at any scientific instrument supply outlet. Pipettes for V, analytical balance weights for m, and ordinary scales or measuring tapes for large d are at least an order of magnitude more accurate than needed for our purposes and also are inherently stable. Calibration and traceability to NBS are possible but pointless exercises for such parameters; careful use of the standards is all that is needed.

Accuracy

Acoustic and electroacoustic measurements are notably less accurate than most other measurements in physical science and engineering. An accuracy of ±12% (approximately ±1.0 dB) of pressure or voltage has widespread acceptance. At USRD, an accuracy of ±2-6% (0.2-0.5 dB) is attainable for calibration measurements, depending on the type of measurement and effort expended. Accuracy here is defined as the range of deviation from the true value within an estimate of 95% certainty.

As a general objective, we seek a parameter accuracy an order of magnitude better than the acceptable hydrophone calibration accuracy when the parameter is routinely measured in every calibration. When the parameter is more of a constant than a variable and is measured infrequently, and presumably with more than routine care, somewhat less than an order of magnitude difference is acceptable.

Some parameters are more easily measured with high accuracy than others. Frequency is an example. When this is the case, higher-than-needed accuracy is specified. Here, the rationale is "the more accurate, the better, provided cost and effort remain constant."

Hydrophone sensitivity and other electroacoustic parameters are relatively insensitive to hydrostatic pressure and temperature. Ideally, they are completely insensitive. Consequently, the measurement accuracy of the environmental parameters need not be very good. Here, again, the measurement accuracy specified below is higher than needed simply because it is easy to obtain.

From these considerations, the accuracy objectives for each parameter are as follows:

±0.1%	voltage, current, resistance, distance, and hydrostatic pressure
±0.5%	density, volume, mass, speed of sound, and acceleration due to gravity
1 part in 10^8	frequency
1 deg	phase
1°C	temperature

Electronic and Electrical Standards

Voltage, Current, and Resistance

At USRD, inherently electrical measurements are traceable to NBS as shown in Fig. 1. Reference standard cells and resistance calibrations are traceable to NBS. The calibrations of these reference standards are transferred to working standards with the high-quality instrumentation shown in Fig. 1. Transfer instruments and working standards may change continually as improved instrumentation becomes available, but the reference standards are not expected to change for many years.

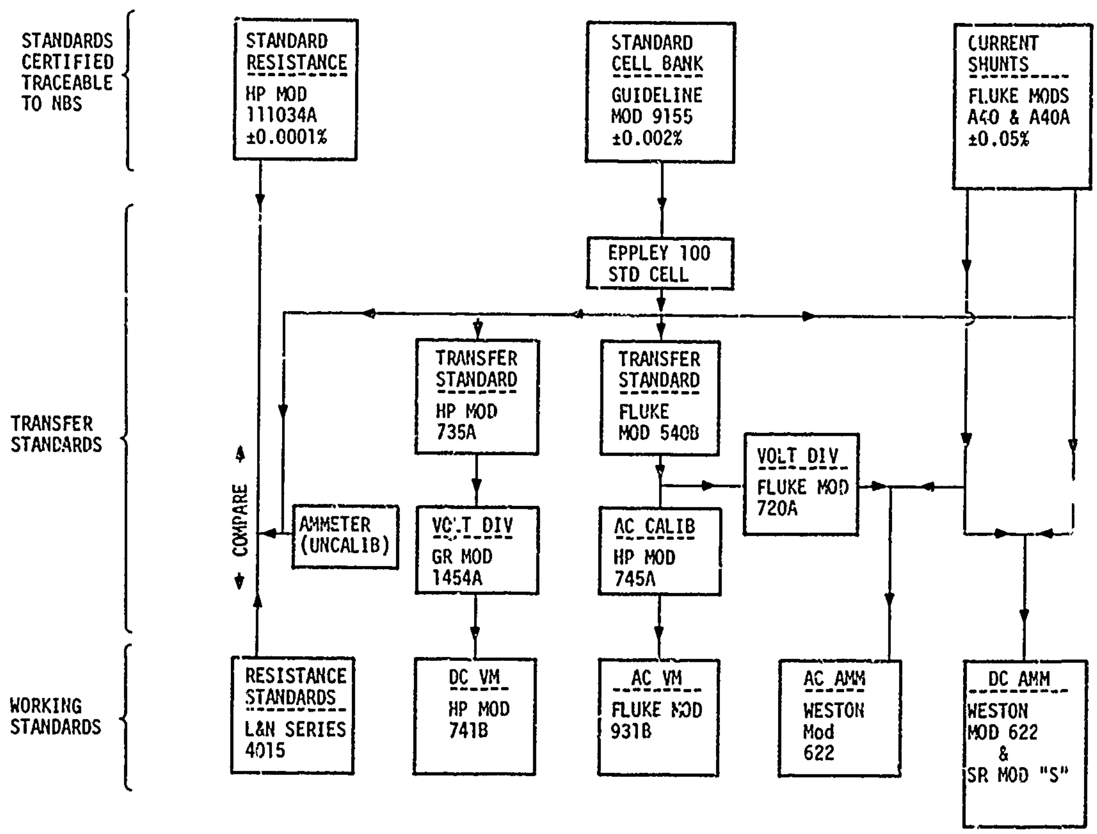

Fig. 1. USRD voltage, current, and resistance standards.

Frequency

A Monsanto Model 3100A Frequency Synthesizer with a drift of ±1 part in 10^9 per day is used as a working standard. It is recalibrated in-house periodically using NBS radio station WWV as a reference standard.

Phase

As noted before, phase is not a basic measurement, but it is important in some special cases. For the record, USRD uses Hewlett-Packard Model 3575A or Ad-Yu Phase Meters.

Speed of Sound

The speed of sound is measured with a commercial velocimeter based on the sing-around circuit that has an accuracy of ±0.01% and is calibrated against pure water. The speed of sound in pure water, in turn, is available from the research paper by Del Grosso and Mader [4], which is the most recent of a long series of research reports on the subject and is accepted as the most authoritative.

Temperature

The USRD temperature standard is a Hewlett-Packard Model 2801A Quartz Thermometer, which operates on the principle that the resonance frequency of a quartz crystal is a function of temperature. The factory calibration, traceable to the NBS, is within 0.02°C--two orders of magnitude better than USRD needs.

Mechanical Standards

Short Distances

USRD standards for short distances are conventional gage blocks used in our machine shop for calibrating calipers. Such blocks are manufactured by several well-known companies--George Scherr, Browne and Sharpe, and Starret. The current set of blocks covers the range 0.1001 to 20.000 in., with an accuracy of ±0.000005 in. at the temperature 68°F and relative humidity 55%. This accuracy is several orders of magnitude beyond our needs for calibration purposes. The gage block dimensions are traceable to NBS. A set of gage blocks calibrated in metric units will be obtained when the metric system becomes more prevalent in mechanical engineering practice.

Hydrostatic Pressure

USRD has several "deadweight" systems manufactured by Manning Maxwell and Moore or Mansfield and Green for calibrating hydrostatic pressure gages. These systems depend on accurate measures of weights and areas and are accurate to ±0.1% to a maximum of 15,000 psi. The systems are periodically sent to a calibration laboratory that certifies its calibration as traceable to NBS.

Reference Data Standards

Density

The density of water as a function of temperature is given on page 384 of reference [5], and also in the form of specific volume and as a function of pressure and temperature on page 2-171 of reference [6].

Acceleration due to Gravity

The acceleration due to gravity is given in Table 2h-4 of reference [6] as 979.26 cm/sec^2 for Orlando, Florida, at 29° latitude and sea level. Correction for the Orlando altitude of 102.8 ft above sea level is negligible. The value 979.3 is more than an order of magnitude more accurate than needed at USRD.

Commercial Standards

As already noted, the reference standards for volume, mass, and large distances need only be regular scientific equipment procured from a reputable outlet.

Rererences

[1] "American National Standard Procedures for Calibration of Electroacoustic Transducers, Particularly Those for Use in Water," Z24.24-1957 (American National Standards Institute, New York, 1957).

[2] "American National Standard Procedures for Calibration of Underwater Electroacoustic Transducers," S1.20-1972 (revision of Z24.24-1957) (American National Standards Institute, New York, 1972).

[3] R. J. Bobber, *Underwater Electroacoustic Measurements* (Naval Research Laboratory, U. S. Government Printing Office, Washington, 1970), Chap. V.

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[5] Felix Franks (ed.), *Water: A Comprehensive Treatise* (Plenum Press, New York, 1972), Vol. 1, "The Physics and Physical Chemistry of Water."

[6] D. E. Gray (ed.), *American Institute of Physics Handbook* (McGraw-Hill Book Co., Inc. New York, 1972), 3rd ed., Sect. 2.